Probabilistic procedure to estimate the macroseismic intensity attenuation in the Italian volcanic districts

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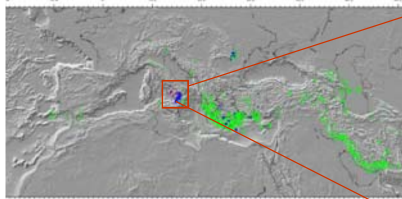
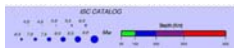
In Italian volcanic areas, we apply a probabilistic procedure for Macroseismic Intensity Attenuation estimates. The procedure, following the Bayesian approach, allows to exploit additional information on historical earthquakes.

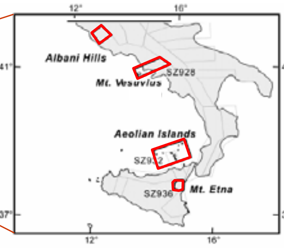
The method, given the epicentral intensity and the site-epicenter distance, begins from selected earthquakes intensity data points and ends at the assessment of the intensity (I_s) probability distribution at a site.

Our probabilistic method provides a probability function matrix that can be directly applied for the computation of probabilistic seismic hazard at the site





From "An Atlas of Mediterranean Seismicity" by Vannucci G., Pondrelli S., Argnani A., Morelli A., Gasperini P. and Boschi E. (2004), Annals of Geophysics, Supplement to Vol, 47, n.1



For the Etna region the CMTE local earthquake catalogue has been used.

For the remaining Italian volcanic districts (Aeolian Islands, Vesuvius-Ischia, and Albani Hills) the CPTI04 Italian seismic catalogue and the DBMI04 associated database have been considered.

Mean features of the procedure

- we identify possible **different decay trends** through a clustering algorithm
- we estimate the **probability distribution** of the intensity at site I_s, conditioned on the epicenter-site distance d and on I_0, by exploiting knowledge from **prior** experience or data (*Bayesian method*)
- assuming the mode of this distribution as estimator of I_s, we **forecast macroseismic fields** given I_0

Step by step...

Step 1. Explorative analysis of a set of macroseismic fields representative of the time-space-size distribution of the Italian seismicity

Step 2. we divide the data set into groups/clusters of macroseismic fields that are similar to each other through an **agglomerative hierarchical clustering** based on the evaluation of distance between each pair of rows of the matrix
we have used the Manhattan distance $d(i,j) = \sum_{k=1}^{p} |x_{ik} - x_{jk}|$.

Step 3. Probabilistic analysis of the intensity attenuation

- the intensity decay ΔI is considered as a random variable like the macroseismic intensity.
- the variable ΔI is discrete and belongs to the domain $\{0, I_0\}$ ⟶ it is reasonable to choose for $I_s = I_0 - \Delta I$, at a fixed distance, the **binomial distribution** $Bin(i_s|I_0, p)$ **conditioned on** I_0 **and** p:

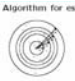
$$Pr\{I_s = i | I_0 = i_0, p\} = Pr\{\Delta I = I_0 - i | I_0 = i_0, p\} = \binom{i_0}{i} p^i (1-p)^{i_0 - i} \qquad i \in \{0, 1, \ldots, i_0\}$$

- ground shaking may differ even among sites located at the same distance ⟶ p random variable

$$Be(p; \alpha, \beta) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \int_0^1 x^{\alpha-1}(1-x)^{\beta-1} dx$$

The prior hyperparameters α, β express our initial knowledge on the decay process that we obtain by examining the three classes of macroseismic fields.

Algorithm for estimation Given earthquakes of the same I_0 in class C



- draw L distance bins $\{R_1, R_2, \ldots, R_L\}$ around the epicenter of width Δr
- assume that the intensity in all the sites within each R_j, $j = 1, \ldots, L$, band follows the same binomial distribution with parameter p_j
- assign the initial value of the parameters on the basis of the macroseismic fields belonging to the same class, but with different I_0;
- we update the hyperparameters α and β through the considered earthquakes and we estimate the parameter p_j, $j = 1, \ldots, L$, through its posterior mean

$$\hat{p}_j = E(p_j | \mathcal{D}_j) = \frac{\alpha_{j0} + \sum_{k=1}^{N_j} i_k^{(j)}}{\alpha_{j0} + \beta_{j0} + N_j\, I_0}$$

- in order to let the p parameter of the binomial distribution for the intensity I_s at site vary with **continuity**, we smooth the estimates $\hat{p}_j$, $j = 1, \ldots, L$ with the method of least squares, using an **inverse power function** $\boxed{g(d) = (\gamma_1/d)^{\gamma_2}}$

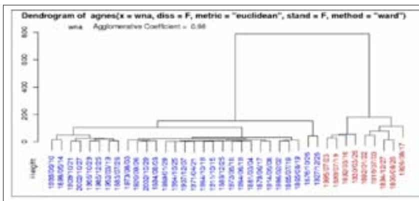
Step 4. Building future scenarios

- binomial distribution at any distance d

$$Pr_{smooth}(I_s = i | I_0 = i_0, d) = \binom{i_0}{i} g(d)^i \, (1 - g(d))^{(i_0 - i)}$$

where $g(d) = (\gamma_1/d)^{\gamma_2}$ is the estimated inverse power function

⟶ the mode i_{smooth} of the distribution is the **predicted value**



#	Location	I_0	Date	#	Location	I_0	Date
12	Etna area	VII	1908/10/21	12	Etna area	VII-VIII	1920/09/26
		VII	1973/06/05			VII-VIII	1952/03/19
		VII	1973/06/18			VIII	1865/06/19
		VII	1984/06/19			VIII	1971/04/21
		VII	1984/10/19			VIII	1984/10/25
		VII	1865/12/25			VIII	2002/10/27
		VII	1986/02/02			VIII	2002/10/29
		VII	1898/10/29			VIII-IX	1879/06/17
		VII	1989/01/29			VIII-IX	1894/08/08
		VII-VIII	1889/12/25			VIII-IX	1911/10/15
		VII-VIII	1898/05/14			IX	1865/07/19
		VII-VIII	1907/12/07			IX-X	1914/05/08
6	Aeolian Islands	VI	1995/07/23	5	Albani Hills	VI-VII	1876/10/26
		VI-VII	1916/07/03			VI-VII	1892/01/22
		VII	1894/11/27			VII	1899/07/19
		VII-VIII	1926/08/17			VII-VIII	1806/08/26
		VII-VIII	1938/03/26			VII-VIII	1927/12/26
		VIII	1892/03/16				
3	Vesuvius-Ischia	VI	1999/08/10				
		VIII	1881/03/04				
		IX	1883/07/28				

Left Panel- Earthquakes clustering. The 38 earthquakes of the dataset in two clusters (**SET 1**, **SET 2**) Clustering was done with the AGNES algorithm (shareware package R). The intensity dataset considered in the present analysis is the same of previous study by Azzaro et al. (2006) on the Italian volcanic districts. **Right Panel- Tab. 1: Macroseismic Intensity dataset.** Etna region: 24 events. Remaining Italian volcanic areas: Aeolian Islands (6 events), Vesuvius-Ischia (3 events) and Albani Hills (5 events).

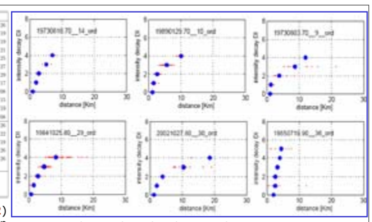
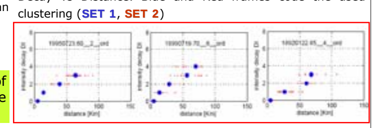
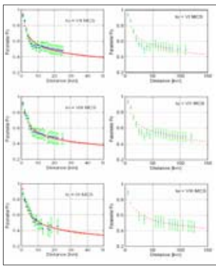


Figure 1: the median distribution of Macroseismic Intensity Decay vs Distance. Blue and Red frames code the used clustering (**SET 1**, **SET 2**)



To summarize information in each macroseismic field, we have chosen some measures of location and dispersion of each set for epicenter-site distances with the same Macroseismic Intensity Decay: median, mean, and 3° quartile.

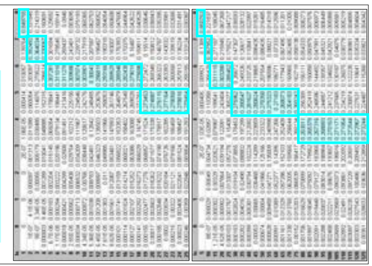


Left Panel:

Estimates of p_j (**blue dots**) for **SET 1** and **SET 2**. 90% highest posterior density (HPD) intervals of the Beta distribution for each p_j (**green bars**). Smoothing inverse power function (**red dots**).

Right Panel:

Matrix of Binomial Probability Function of intensity Io = VIII MCS for **SET 1** and **SET 2**. In light blue is the mode for each bin of distance.



The decay trends produced by the clustering algorithm match well the ones published in the past (Azzaro et al. 2006). This suggests that the method could be successfully applied to other cases.

Open questions:

- Most of the earthquakes considered have epicentral intensity VII or VIII (MCS): this makes the probability functions of Is conditioned on the other Io (VI and IX) not very reliable.
- The method should be validated using earthquakes not included in our dataset of Table 1, on the basis of probabilistic measures of the degree to which the model predicts the decay in the data points of a macroseismic field (Rotondi and Zonno, 2004).

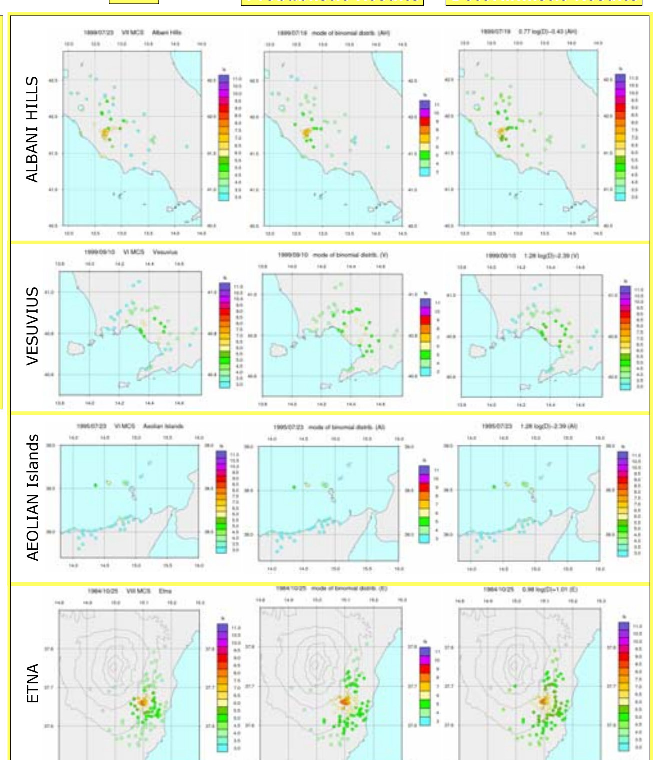
Data | **Probabilstic Results** | **Deterministic Results**

ALBANI HILLS

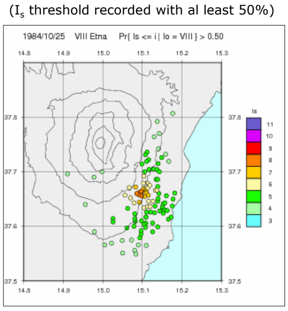
VESUVIUS

AEOLIAN Islands

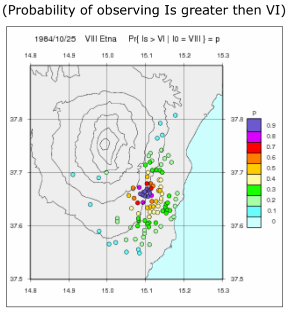
ETNA



Probability $\{ I_s \leq i | I_0 = VIII \} > 0.50$
(I_s threshold recorded with al least 50%)



Probability $\{ I_s > VI | I_0 = VIII \} = p$
(Probability of observing Is greater then VI)



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